

EFFECTS OF ACIDIFICATION ON FORESTS AND NATURAL VEGETATION,
WILD ANIMALS AND INSECTS

B.A. MOLSKI and W. DMUCHOWSKI

Botanical Garden of the Polish Academy of Sciences, skr. 84,
02 973 Warszawa 34 (Poland)

ABSTRACT

The dying-forest syndrom occupies scientists and foresters in Central Europe. It is generally agreed that the atmospheric pollution is a major factor (SO_2 , NO_x , ozone) causing the damage. However, the mechanisms involved in forests deterioration and especially the methods of evaluation of these damages are not completely understood and agreed upon among scientists. The evaluation of dry and wet deposition of pollutants and their forest growth deterioration effects should be based on the chemical composition of leaves (pollutants and nutrients), growth increment and litter decomposition.

INTRODUCTION

Acidification of environment means "wet" acidifying deposition in the form of rain, snow and fog, and "dry" in the form of gases and dust. The main acidifying compounds in the atmosphere are H_2S , SO_2 - SO_4 and NO_x . Emissions of sulphur per year to the air on a worldwide basis by natural processes (volcanic activities, fires, metabolism of organisms and others) are much larger (150⁶ to 470⁶ tons of S) than the human activities (70⁶ - 284⁶ tons of S), but the emissions caused by man occur only over industrialized regions covering less than 5% of the earth's surface. In these regions (Europe, Eastern North America, Japan) man-made S emissions exceed the natural emissions by a factor of 5 to 20 (ref. 1-4) (see Fig. 2). Emission of NO_x arises both from the nitrogen in the and a high temperature fixation of atmospheric nitrogen. The man-made world emission of nitrogen is about 75⁶ - 100⁶ tons per year (ref. 4). Natural processes, depending on various sources of estimation (ref. 1-4), contribute of 80⁶ - 270⁶ per year in the form of NH_3 and of 60⁶ - 430⁶ tons in the form of nitrate from NO_x (ref. 3).

Very high emissions of S and N within large industrialized regions with many local sources of emissions overlapping with their zones of influence on vegetation produce a very big area leading to the destruction of forests (see Tab. 1) and major changes in the vegetation composition on wide areas in Central Europe (see Fig. 1). However, even in these areas one can find places with a smaller deposition of pollutants due to the local wind velocity, precipitation and the possibility of accumulation by vegetation, etc. In areas of scattered relatively small sources of emission, as for example in Spain, Northern Finland and Northern Sweden the dispersion of SO_2 and NO_x is only local and depends mainly on a smaller deposition up to several kilometres from the source of emission.

The total deposition of sulphur, dry and wet, is very high near the emission source. In more remote areas the wet deposition assumes greater importance. In dry deposition (SO_2) atmospheric lifetime is from a few hours up to two days and the mean transport distance up to a few hundred kilometres, diminishing rapidly with distance. SO_4 has 3 to 5 days of a lifetime and the mean transport distance is about a thousand km or more. The most damaging effects of air pollution are in areas where a high background pollution is enlarged by local sources of pollution, which is demonstrated by Fig. 3 representing Poland, where a high transboundary air pollution from Czechoslovakia and the German Democratic Republic produces high acute damages to forests in south-western Poland. Nevertheless the local sources of emission also contribute intensively, increasing the accumulation of pollutants. The map of sulphur accumulation in pine needles in Poland suggest that the transport is not so remote. It seems to be in contrast to the evaluation done by meteorological models of pollutants diffusion in the world. It may also be possible that pollutants accumulation by vegetation decreases rapidly with the distance from the source. However, only a mapping of air pollutants accumulation in forest trees in a large area, such as the whole of Central and Northern Europe, may bring a better understanding of transportation and accumulation. In Europe more than 6 million ha of forest are damaged, and about 1 million ha of that is seriously damaged (see Tab. 1 and 2). There is no doubt that at least 1 million ha of seriously damaged forest is caused by air pollution, at least as the primary cause of decline. Without air pollution and its wide dispersion, as well as its direct and indirect influence, the recent

forest damage could not have occurred in the present form and extent. Nevertheless not all scientifically proven evidence indicates that the air pollutants are causing the most of the present forest damages. Many areas of damaged forests are effected by drought, fungal diseases, insects and windbreaks. But the wide dispersion of SO_2 , accumulated from year to year, due to high smoke stacks, NO_x from growing road traffic and higher combustion temperatures in furnaces and ozone formation, are no doubt a steadily increasing negative factor to vegetation, soil and water contamination leading to toxic levels of accumulation. The damage process is difficult to study empirically, since several pollutants are active at the same time leading to synergistic effects. The recent widespread and increasing forest damages are presumed to be caused by a complex set of factors, biotic, abiotic, climatic, man-made, etc. whose relative importance varies according to site conditions. The effect of acid precipitation on the leaf surface of trees and the soil causing the leaching of nutrients is especially dangerous.

There are several hypotheses about the forest decline in Europe: The acidification - aluminium toxicity hypothesis developed by Ulrich (ref. 11) holds that the natural acidification of forest soils is accelerated as a result of the deposition of acidic and acidifying substances from the atmosphere leading to increased concentrations of soluble aluminium ions. Aluminium toxicity results in necrosis of fine roots and a decrease in the water uptake and death of the trees, particularly during drought periods.

The ozone hypothesis based on field observations of foliar symptoms and measurements of ozone concentrations as well as on controlled exposures of seedlings of various tree species presumes that ozone leads to direct damage of leaves, weakening of cell membranes and nutrients to be lost from damaged cells.

The aluminium deficiency hypothesis based on soil and foliar chemical analyses in high elevation spruce stands shows an extreme magnesium deficiency in trees and big supplies of nitrogen and calcium leading to the disturbance of these trees growths (ref. 12).

The ammonium hypothesis (ref. 13) suggests that a nitrogen build-up in soil and plants due to the high amounts of atmospheric fallout is causing formation of cells with large volumes that are easily attacked by wind, drought and parasites.

The general stress hypothesis (ref. 12) regards the whole-plant carbohydrate economy disturbance due to a decrease in the net photosynthetic production and the associated diversion of carbohydrates to less mobile and potentially toxic secondary substances leading to a poor development of fine roots and mycorrhizae and to foliar decline, to be the major effect of air pollution.

One more hypothesis as to the explanation of trees death due to air pollution may be added - the theory of a suppression of the symplastic ways of translocation of carbohydrates from leaves to roots. A decrease in the carbohydrate production and a reduction of the radial growth of trees cause first of all a disturbance in the phloem growth (ref. 14.). Sieve tube elements function only for a few months and to ensure permanent supply of organic substances from the tree crown to roots, there has to be a continuous growth of the new layers of phloem through the whole tree trunk. Any decrease in this pathway leads to the starvation of the root system including the continuous growth of fine roots which condition the proper uptake of water and mineral nutrients as well as the starvation of mycorrhizic fungi. In this way a decrease in the foliar function due to air pollution causes a decrease in the roots function as to water uptake. This reduction of water uptake has deleterious effect on the crowns function leading finally to a further decrease in the photosynthetic activities of leaves. A tree without fine roots behaves as a piece of branch put in a bottle of water - a mechanical water uptake can not ensure a normal growth and leads to the death of the tree. A very common symptom of abundant formation of adventitious shoots on the upper sides of branches located as near the ground as possible in firs, pines and spruces in polluted areas serves twofold: in lower parts of the forest there is a much smaller air pollutants' accumulation in needles due to the decrease of wind speed, and the translocation way from leaves to roots is shortened, facilitating sieve tube's formation.

The theory of suppression of the symplastic way of translocation contributes also to the explanation of the very high susceptibility of fir to air pollution, since the fir phloem sieve tubes are the most short-lived and only a few layers of phloem cells are formed per year (ref. 15 and 16). It also explains why the older and taller trees are more damaged by air pollution than the young and small ones - in young trees the translocation

from roots to leaves is much shorter than in old ones. Table 2 illustrates forest tree damages broken down to tree species in selected countries from which such data were available. The table represents seven species or genera in four countries and groups of species in two countries. The data indicate that, although there are differences in separate countries, coniferous trees are more susceptible than broadleaved trees, and that *Abies alba* is always the most susceptible tree species. Silver fir (*Abies alba* Mill.) is one of the most valuable forest trees in middle-elevation mountain ranges in Central Europe. A periodically appearing disease has been known since the beginning of the last century, but the present extent of the decline is so wide that in many parts of Europe this species will be totally lost as a forest tree. The tall, above 60-80 years old, trees are affected more seriously than the younger ones. Studies of pollen and reconstruction of *Abies* movement in the last 5000 years (ref. 18) indicate a continuous oscillation of the area of distribution of this species and a migration towards the north or the south. The present decline may be the next "wave" towards the south. But there is no doubt that man-made air pollution is one of the major factors of the disappearance of the species.

Pines and spruces, in Europe, as well as in the USA (ref. 19) are among the most suffering species for the last 20 years. During the last few years there is increasing damage to broadleaved species, such as oak, beech and sycamore maple. Species of lorch and birch are so far the most resistant to air pollution, however with heavy pollution they suffer from early leaf fall and a disorder of branching. The forest decline in Europe and intensive research of the USA and Canada absorbs not only the public opinion, but also the foresters and scientist. A lot of different explanations exist as to why the damage expands. The controversy between natural causes of forests' decline such as diseases, insects, droughts, etc., as primary stresses and air pollution, may be solved by a chemical analysis of leaf content.

Any of the elements present in the tissue of a plant as constituents of organic molecules, or as ionic forms or deposits of insoluble salt, may be in deficiency, abundance or accumulation in plants may reach a toxic level. There is a close relationship between content of pollutants in air and their accumulation in leaves. Fig. 4 represents studies of the sulphur content in pine needles in Poland. It illustrates the great difference in

sulphur content between pine grown in clean areas and heavily polluted ones. It proves the usefulness of scotch pine (*Pinus silvestris* L.) as an indicator and an accumulator of environmental pollution.

The pine served for constructing the map of pollution for Poland presented in Fig. 1 and Fig. 2.

The chemical composition of leaves (needles) may bring valuable information about stands' decline not only because of pollutants, but also because of nutrients' availability. Potassium or nitrogen deficiency in upland organic soils in Britain caused a yellowing of needles (ref. 6.) In West Germany the yellowing of older needles is connected with magnesium concentrations. Growth-limiting nutrient levels are not adequately documented; studies of a dose-response curve for the growth of different forest tree species are needed, which means experimentations with a wide range of nutrients and pollutants. An extensive foliar analysis related to air pollution and a soil analysis may also contribute important information related to the understanding of the forest decline. Fig. 5 represents the composition of the fourteen most important elements in pine needles in fairly clean and heavily polluted areas. However one important factor has to be observed - the collection of the foliar materials has to take into consideration the time of the growing period and the particular turnover of elements by plants in that particular time. The second part of the winter seems to be best because at this time there is the highest content of pollutants, and all other elements are not in any physiological transformation.

Any assessment of forest decline is difficult without analyses of growth and yield of wood and these must be based on longterm studies of at least 5-10 years.

The assesment may be made on the basis of tree ring analyses of the cores of sample trees on permanent trial plots, as well as on the basis of periodic measurements of stands on permanent trial plots with consideration to all trees removed from the stand between the measurement periods. Clear relationships were noticed between the extent of needle losses and increment reduction. In the northeastern U.S. (New York, Vermont, New Hampshire and Maine) a study of increment cores from 3000 red spruce trees showed that the reduction in growth rates began around 1960. In the 1980 as the growth rate is from 13% to 40% less than it was in the highest growth

year 1960. In the southeastern U.S. (Georgia, South and North Carolina and Virginia) the diameter growth rates of loblolly, shortleaf and slash pines have decreased by 20% to 39% over the past 20 years (ref. 6). These changes in growth rates do not appear to be related to stand age or density.

Experiments with the effects of a continuous springtime fumigation with SO_2 on CO_2 uptake and structure of the annual ring in spruce done by Keller (ref. 20) proved that SO_2 concentrations, which do not cause the development of visible symptoms of injury in spruce, reduced the photosynthetic activity and cambium growth. The production of the annual ring decreased and the amount and density of late wood was reduced. The reduction of the growth of several forest trees in experimental and field conditions without visible foliar has been documented many times (ref. 19 and 21).

Besides the foliar analysis of nutrients and pollutants content and tree ring analyses, the next very important indicator of forest decline is the decomposition rate of the litter cover, which in the high concentrations of SO_2 increases because of an inhibition of pine litter which may be the result of declines in the microbial activity, deficiency in critical system nutrients, together with an accumulation of toxic materials, and may be classified as a "carpet effect" in the polluted forest. The litter bags method may be used for the study of field decomposition rates (ref. 21).

High and permanent air pollution in a forested area leads to serious damages finally killing almost all of the plants and creating a desert. In Poland around some big old factories with heavy pollution one can distinguish the following three distinct zones (ref. 22):

- Where air pollution is damaging trees, the forest changes to a poor-quality woodland zone (mostly birch - *Betula verrucosa*) and occasionally oak, poplar, hagberry.
- Where air pollution is lethal (about 2 metres above the ground) poor-quality woodland changes to industriogenic shrub communities (ref. 23) of *Pinus silvestris* growing as shrubs about 1 - 1.5 metres high with some *Juniperus communis*, *Salix rosmarinifolia*, *Quercus robur* and *Q. rubra*, *Calluna vulgaris*, *Arabis arenosa*, *Rumex acetosa*, *R. acetosella*, *Festuca ovina*, *Molinia coerulea*, *Deschampsia flexuosa*, *Ceratodon purpureus*, *Bryum caespiticium* and a few more species.

The biomass production of this type of vegetation is about 3000 to 5000 kg of dry matter of woody plants per hectare and that is about 1 to 4% of what can be produced in such an area by normal vegetation undamaged by pollution.

With still higher pollution near the factories, shrubs communities change to an industriogenic grassland with *Deschampsia flexuosa* and *Calamagrostis epigeios*, *C. vilosa* and similar grasses or *Silene inflata* with *Arabis arenosa* communities. If the contamination is still higher in areas adjoining factories, the grassland changes to naked mineral soil with scattered small groups of *Silene inflata*, *Arabis arenosa* and *Agrostis vulgaris* in some places. In other places *Festuca ovina* or *Deschampsia flexuosa* grow.

Industrial pollution acts as an agent of selection causing drastic changes in the composition of a forest, eliminating first all the trees that are more susceptible to pollutants. Finally only part of the original population is maintained which was able to withstand the polluted environment. The development of electrophoretic techniques for the analysis of isoenzymes and studies of provenances and clones of different species of trees reveals that an increased tolerance to pollutants may have a genetic basis (ref. 24). Differences between provenances in *Picea abies* can be so great that they may be comparable with differences between species. The most SO_2 - tolerant provenances of *Picea abies* are comparable in resistance to *Picea pungens*. Provenances of *Picea abies* from mountains and the north are usually more resistant than lowland and Southern provenances (ref. 25 and 26). Studies of pollution resistance in some Finnish scots pine provenances showed that the more resistant northern pine has a greater xeromorphism (ref. 27). Significant difference in the sensitivity to SO_2 in *Larix decidua* and the hybrid progeny of *Larix decidua* x *Leptolepis* were several times indicated (ref. 28, 29, 30). Kornosky (ref. 31) showed differences in the resistance to O_3 in *Fraxinus pennsylvanica*.

In spite of a very short period of pollution action on plants there is already evidence of some plant populations' having adapted to air pollution (ref. 32). Populations of herbaceous species growing under heavy soil or air pollution for many generations have formed races genetically adapted to such conditions. Adaptation examples or variability in response to pollutants were described several times for different species, as *Silene*

dioica adapted for a high content of copper carbonate (ref. 33.). *Geranium carolinianum* to sulphur dioxide (ref. 34), *Agrostis tenuis* to copper and zinc in the soil (ref. 35), *Lolium perenne* to SO_2 (ref. 36) etc.

It takes many generations to produce a new resistant line. In trees it is a very difficult task due to a long period from germination to seed production. However, it is known already that many tree species such as *Pinus silvestris* L., *Picea abies* L., *Larix* spp., *Pinus ponderosa* laws, *Pinus contorta* Daugl., *Pinus strobus* L. and *Pseudotsuga taxifolia* Brit. represent a great variability also in their sensitivity to SO_2 , fluoride, oxidants (ref. 37).

Variability in tree species, a great area of distribution, and old vegetative reproduction as well as new biotechnological methods of breeding may bring results much faster than it might be anticipated. However, a wide international cooperation is needed in the selection of resistant or less susceptible individual trees in areas of permanent pollution as well as in the development of new methods of propagation and breeding.

Research on the heritability of tolerance to air and soil pollution in *Deschampsia caespitosa* showed that it is due to additive gene effects (ref. 32), so it should show a rapid response to selection. Examination of the segregation pattern of progenis of controlled crosses, as shown for *Anthoxanthum odoratum*, and other species, indicates that the tolerance to pollution might be determined by polygenes and with some dominance to the tolerant parents (ref. 38). The reduction of pollution is the only way to save vegetation and forests, first of all in an immediate emergency action in Europe but also in long term activity. But selection and breeding for resistance to air and soil pollution of trees, shrubs and herbaceous plants should also one of the major activities of biologists since it is doubtful that we shall reach absolutly clean air and soil in our present world, which is overcrowded, over-armed and produces too many unnecessary products.

The breeding of trees and shurbs resistant to pollution should go in the direction of true accumulators of toxic materials with as little internal damage as possible.

In many countries of Central Europe especially in Poland, Czechoslovakia, the Federal Republic of Germany, game population increased greatly. Hoofed game are now a very important cause of damage to young forest stands by browsing and fraying and even to older stands by peeling

bark. In Poland 250.000 ha of forest are seriously damaged by game. Exceedingly large game populations endanger the results of generations in particular with regard to deciduous tree species and spruces in Fed. Rep. of Germany, and pine, fir and spruce in Poland.

In one of the most polluted forests, Niepolomice, there are: red deer, 0.02 individual per ha in deciduous forests and almost 3 times as many in the coniferous forests. The roe-deer population is twice as dense in the deciduous forests 0.29 - 0.33 individual per ha, than in coniferous ones. The wild boar range from 0.009 to 0.02 individual per ha (0.014 average) (ref. 39).

In Poland there are more than 250 european bisons, about 6 000 moose, 80 000 red deer, 80 000 wild boars and more than 400 000 roe-deer altogether.

The browse of wild animals in polluted areas is contaminated with sulphur and heavy metals, which results in an increase in their concentration in deer antlers. In the Niepolomice Forests with a heavy pollution deer antlers show a 30% increase in sulphur, and a 10% increase in heavy metals (ref. 39). The pollution of food is blamed for a drop in the quality of antlers in this Forest - in the last 20 years there has been a 32% decrease in the average weight of antlers, a 29% decrease in antler length, and a 25-30% decrease in trophy quality as estimated from international CJC tables.

Wildlife and especially big game, do not decrease their population due to air pollution, however they do suffer from the pollution of food, which should have its influence in future.

The development of insects is in some groups closely related to air pollution, in others not. Leaf-eating insects are usually reduced by an increased air pollution, but not in all genera, secondary pests usually increase their populations.

In polluted forests the number of secondary pests increases, especially as to cambiohagous insects. The most abundant species are *Blastophagus piniperda* L. and *Pissodes piniphilus* Host. The less viable trees attract cambiohagous insects, probably due to either a decreased water content in the tree and a decreased osmotic pressure, or to an increased content or modified composition of etheric oils. Another assemblage of cambiohagous species includes *Blastophagus minor* Htg.,

Pityogenes Bidentatus Hbst., *Pityophthorus pityographus* Rotz., *Pissodes pini* L., *Monochamus galloprovincialis* Ol., *Acanthocinus aedilid* L., *Crioecephalus rusticus* L., *Rhagium inquisitor* L., and *Callidium aenum* Deg. The occurrence of such a diversity and abundance of pests results in a considerable injury to the trees (ref. 39).

A decline in grasshopper populations (*Melanoplus* and *Eritettix*) in experimental sites of the polluted area of Colstrip (USA) has been indicated. Similarly, a decline in saprophagous and necrophagous beetles has been described, which leads to an alteration of the decomposition rates of litter (ref. 21).

Industrial pollution intensifies the action of some phytophagous insects on forests. *Exoteleia dodecella* and *Rhyacionia bouliana* in young pine plantations intensify their injurious effects. Others, mostly *Cynips lignicola* Htg., increase their abundance in young oak plantations. These insects cause damage to buds, and due to their mass occurrence they inhibit the height growth of trees, reducing the growth of shrubs (ref. 39).

The forest inventory of the infestation with insects and fungi of trees in the Federal Republic of Germany reveals that in contrast to biological research results, trees with foliage damage symptoms have less trees infested with fungi and insects (severely damaged - 9.9%) than trees without symptoms of damage (13.8%), but the bark beetles develop 3 times better on damaged trees than on healthy ones (ref. 7).

The Polish forest inventory (ref. 40) shows that fungi and leave-eating insects develop with no connection to air pollution damages, but populations of secondary pests develop much faster in polluted areas of forests.

CONCLUSIONS

1. The massive forest damage in Europe and North America, in spite of other causes as droughts, fungal diseases, insects and windbreaks are triggered off by air pollution as the primary cause and only a decrease of air pollution may save the forest from a final destruction.
2. The long-range transboundary transport of air pollutants might have a definite direct influence on the vegetation in neighbouring countries, where foreign imported air pollutants overlap with local pollution. It is difficult to prove the strongly negative direct effects of these pollutants throughout the countries to third countries over more than 1 000 - 1 500 km, but the indirect effects of acid rains, mostly through the soil, are obvious, especially in areas prone to acidification.
3. Adequate methods of evaluation and a large-scale mapping of forest areas, based on pollutants accumulation in forest trees, may bring a full picture of the real threat and the sources of damage. The research and evolution of forest damages should be carried out under the supervision of the UNEP.
4. A wide international cooperation is needed in the selection of resistant or at least less susceptible individual trees in areas of permanent pollution, as well as in the development of new methods of propagation and breeding. A variability in tree species, a great area of distribution, and old-fashioned vegetative reproduction as well as new biotechnological methods of breeding may bring results much faster than it might be anticipated.

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Table 1

Forest damages in selected countries based on ECE data (ref. 5, 6) for F.R.G. on Federal Government data (ref. 7) for Poland on the Main Statistical Office data (ref. 8).

Country and Year of date collection	Total forest Area of forest area damages				Region	
	1000	% of	1000	% of		
	ha	land	ha	forest area		
Spain	1979	15 260	30.5		Local sources	
Italy	1983	5 341		278	5.2	Local sources
France	1979	14 543	26.7		3	Rhone and Sein
Alsace + Lorraine	1984	428			40.6	Valley
Franche Comté	1984	258			35.4	
Netherlands	1984	281	8.6		49	Scattered
Luxemburg	1984	87			18.5	
Ireland	1979	317	4.6		3	Local sources
Great- Britain	1979	2018	8.8		3	Local sources
Denmark	1984	465	11.6		3	North-western
State owned		105		3	3	Jutland
Finland	1979	23 321	76.3	120	3	Local sources
Norway	1979	8 330	27.1		3	South-eastern Norway
Sweden	1983	26 424	64.2	200	3	South Sweden
Switzerland	1983	1 052	26.5		34	Northern centers, Valaris
Austria	1979	3 754	44.8	330	9	Upper Austria Stryria, Tirol
Hungary	1985	1 594	17.3	170	10	Local sources

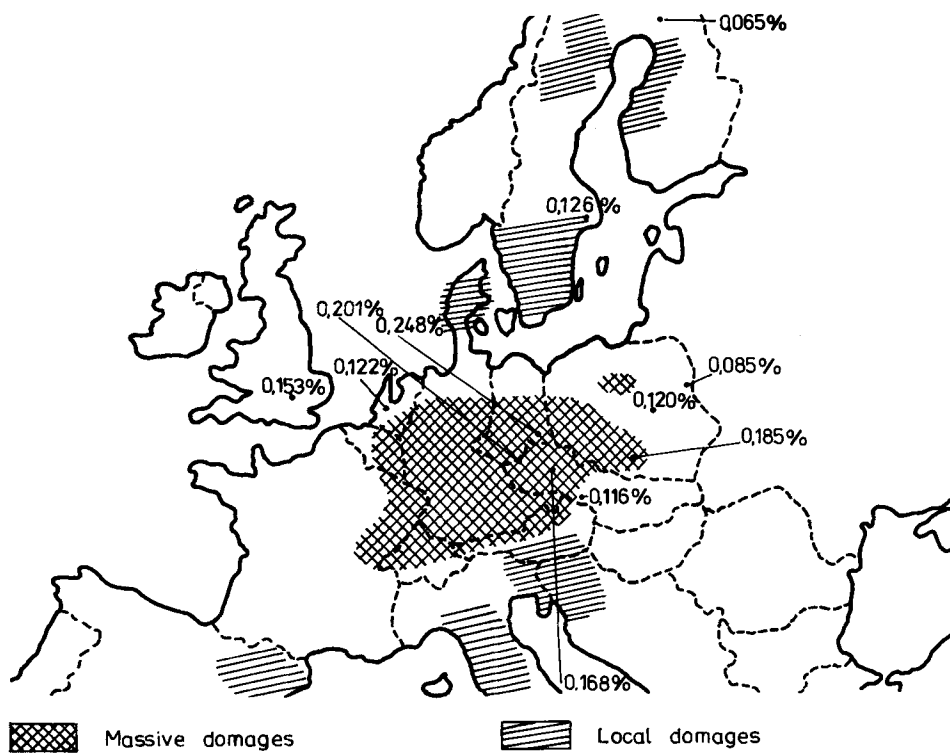
Czechoslovakia	1979	4 535	36.1	450	10	Ore Mnt., Iser Mnt.
F.R.G.	1982			560	8	Aglomeration areas, ridges of central highlands
	1983	7 318	35	2 545	34	
	1984			3 698	50	
	1985			3 824	52	
Poland	1971	8 432	27	239	2.8	Sudety Mnt., Upper Silesia
	1980	8 622	27.6	383	4.4	
	1983	8 639	27.6	465	5.4	Krakow, Torun, Wloclawek Reg.
	1984	8 645	27.6	571	6.6	
Canada	1985	326 000	36	1100	1	Local sources

Table 2

Selected information of forest damages broken down by tree species based on data for F.R.G. (ref. 7), for Poland (ref. 17) and other countries (ref. 6).

Country species	Year of survey	Damage stage %				Area of tree species	
		0 without damage	1 slightly damaged	2 moderately damaged	3 + 4 severely damaged and dead	1000 ha	% of total forested area
F.R.G.							
Picea abies	1983	59.1	30.0	10.0	0.9	2.951	40
	1985	47.8	28.2	21.4	2.6		
Pinus silv.	1983	57.0	32	10	1.0	1.464	20
	1985	42.5	40.5	15.3	1.7		
Abies alba	1983	24.0	27	42	7.0	176	2
	1985	12.8	20.5	50.3	16.4		
Fagus silv.	1983	73.7	22	4	0.3	1.250	17
	1985	45.5	40.1	13.1	1.3		
Quercus spp.	1983	84.8	13	2	0.2	615	8
	1985	44.7	38.9	15.7	0.7		
Others	1983	83.6	9	7	0.4	950	13
	1985	69.5	22.7	6.7	1.1		
Total	1983	65.6	24.7	8.7	1.0	7.371	100
	1985	49.1	32.7	17	2.1		
Poland							
Picea abies	1983	66	23	10	1	631	7
	1983	73	25	2		6.267	72
Italy							
	1983						
Picea abies		91	7	2	1	449	
Abies Alba		92	4	2	2	117	
Pinus spp.		95	4	1	1	478	
Fagus sylvatica		93	5	1	1	761	
Castanea sativa		93	5	1	1	760	
Oaks/deciduous/		95	4	1	1	1.137	
Oaks/evergreens/		98	1	1	1	188	
Netherlands							
	1984						
Total		50.5	40.0	8.0	1.5		
Coniferous		43.5	44.0	11.0	1.5		
Broadleaved		67.0	28.3	3.7	1.0		
Pinus silvestris		34	51	12	3	113	
Pinus spp.		57	34	8	1	16	
Picea abies		62	28	7	3	13	
Pseudotsuga men.		50	39	9	2	16	
Quercus spp.		57	38	4	1	44	
Fagus sylvatica		71	24	1	1	9	
Broadleaved others		74	23	2	1	47	
Luxemburg							
	1985						
Conifers 60 y.o.		59.0	34.7	5.8	0.5		
60 years old		90.5	6.4	1.7	1.4		
Broadleaved		71.6	23.7	4.0	0.7		
Total forests		79.1	16.9	3.0	1.0		
Switzerland							
	1984						
Coniferous		62.4	28.0	8.2	1.4		
Broadleaved		75.1	21.7	3.0	0.2		

Fig. 1

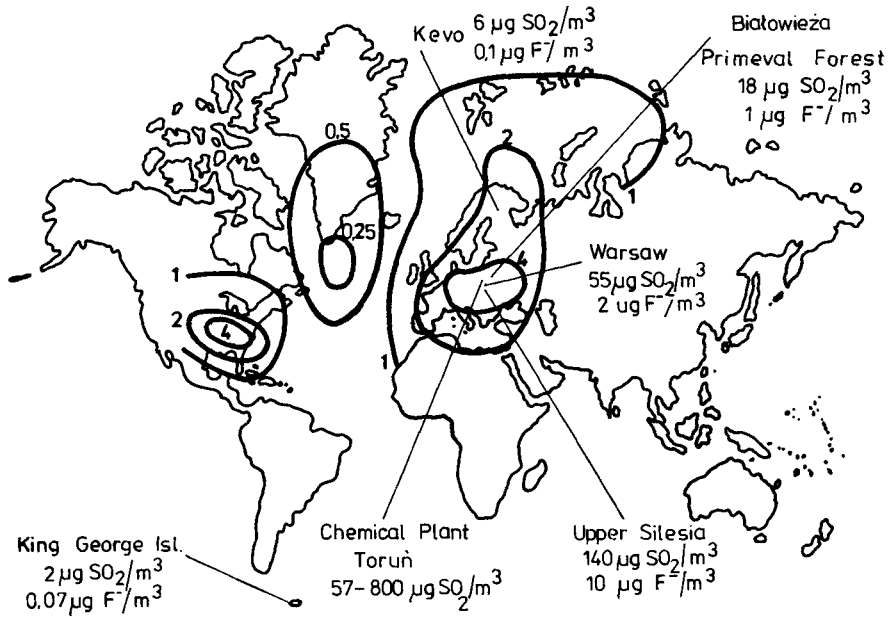


These figures represent the percentage of sulphur in Scot pine needles.

Distribution of forest damages in Europe due to air pollution as a primary source - compare Tabel 1.

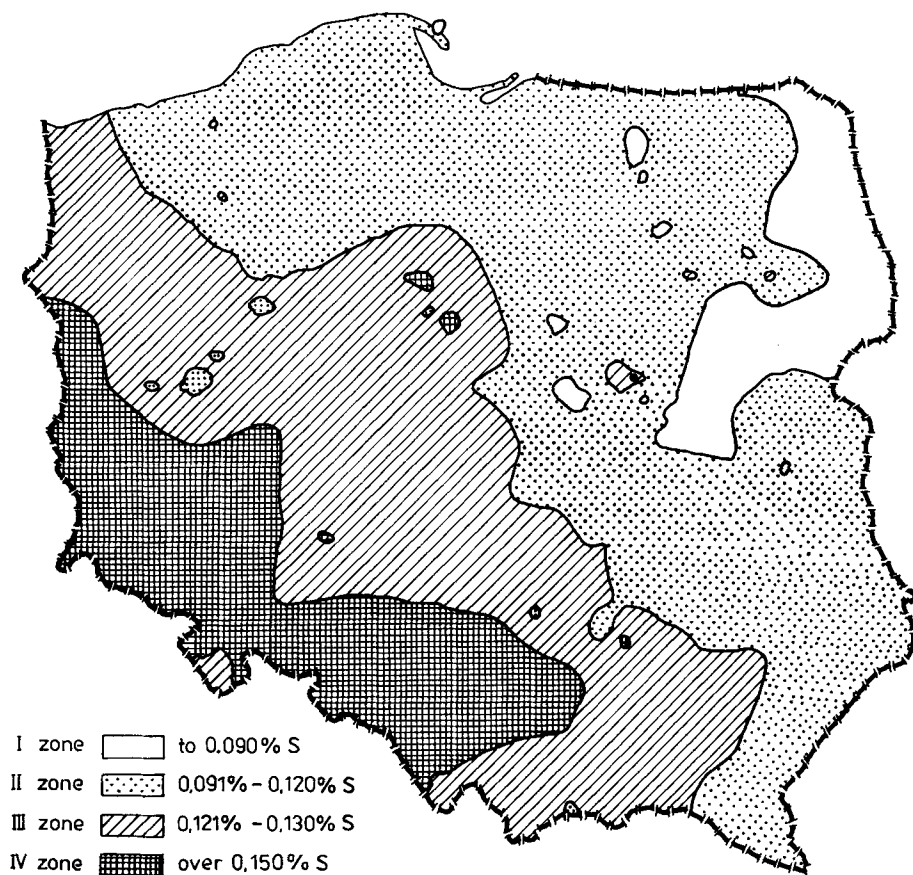
Area with the massive damages has as a rule, a high content of sulphur in pine needles (above 0.15%) areas with local damages about 0.10 to 0.15%, and fairly clean below 0.10.

Fig. 2



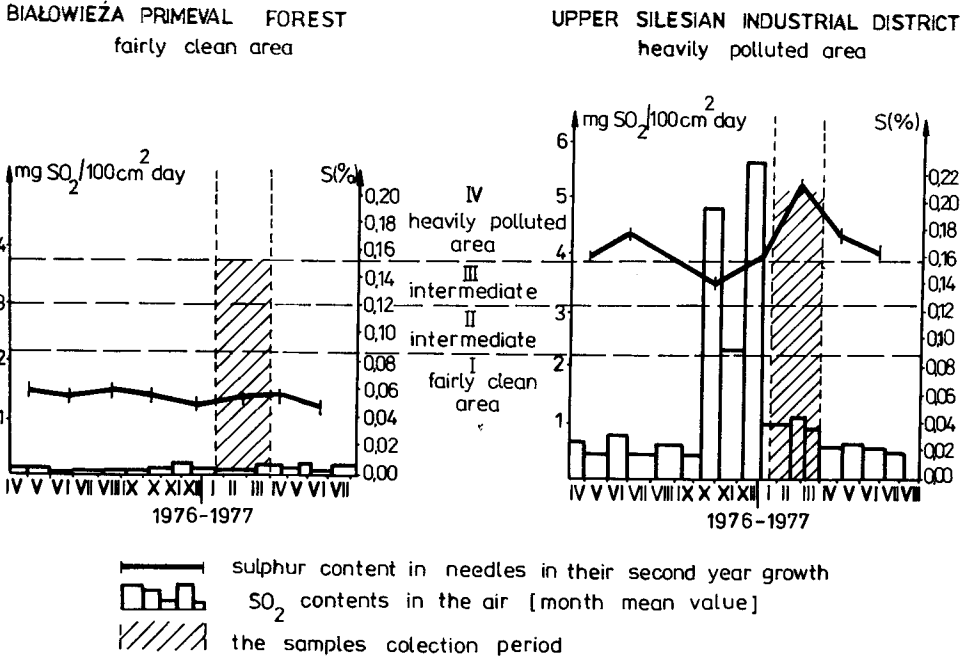
A map of the world showing sulphate-sulphur concentrations, excluding sea spray sulphate, in winter in SO_4-S $\mu g/m^3$ (data from EMEP), and concentrations of SO_2 and fluorine compounds in the air of the different world localities (ref. 9 and 10). The importance of the North-East of the USA and Central Europe is obvious, but within the centres of global emissions a big variation of air pollution always occurs (see figures for different places).

Fig. 3



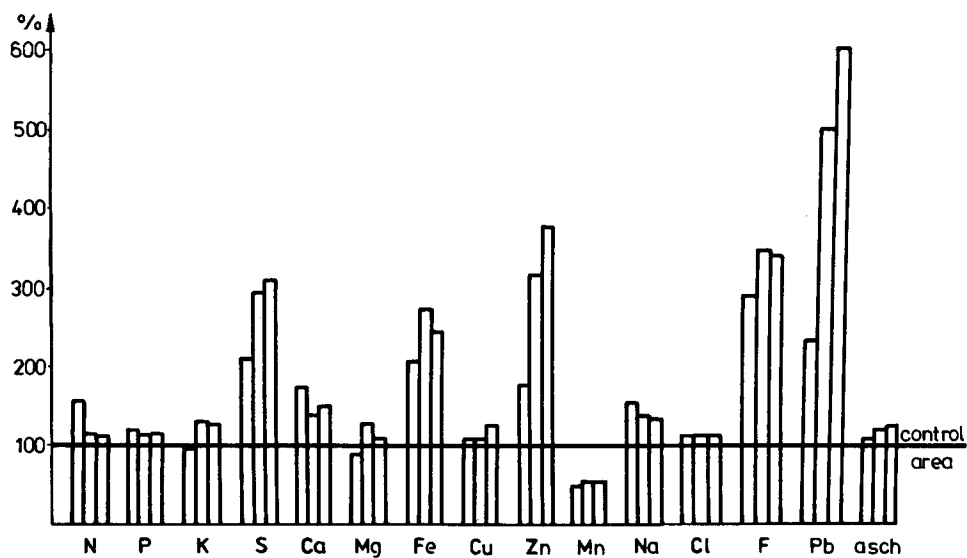
Sulphur accumulation in pine needles in Poland as a bioindicator of air pollution. Zone I represents the level of sulphur in needles as found in clean areas, zone IV represents at least the double content sulphur and is considered as toxic for pine, spruce and fir. In the two intermediate zones there are commonly less contaminated small local areas.

Fig. 4



Accumulation of sulphur in pine needles in relation to the sulphur content in the air. The content of sulphur fluctuates through the year, especially in heavily polluted areas, depending on the sulphur content in the air, and the physiological transformation within the plants throughout the growing season. These data served to construct the map presented in Fig. 3.

Fig. 5



The chemical composition of pine in fairly clean areas shown as a 100% line and in heavily polluted areas as a per cent of the content of the clean area. The content of each element is shown in three columns - the first represent the current growth, the second - previous year's growth, and the third column the third year's growth of needles. The biggest changes are in the contents of polluting elements as Pb, Zn, F and S - an increase of 300% - 600%, and only Mn concentration decreases by 50% in comparison to the control area.